## METHOD AND APPARATUS FOR PERFORMING
## MOTION ANALYSIS ON AN IMAGE SEQUENCE

This application claims the benefit of U.S. Provisional Application
No. 60/190,819, filed March 21, 2000, which is herein incorporated by
reference.

This invention was made with U.S. government support under
NIDL contract number NMA20297D1033 and DARPA contract number
MDA97297C0033.  The U.S. government has certain rights in this
invention.

The invention relates generally to a method and apparatus for video
processing and, more particularly, to a method and apparatus for
performing motion analysis on an image sequence.

## BACKGROUND OF THE DISCLOSURE

Current research efforts have used prototype systems to perform
data mining or data analysis of spatial and/or temporal information
within an image sequence.  The prototype systems may perform data
mining in accordance to a theoretical framework from Chorochronos, a
European-based research network for spatio-temporal database systems.
Chrorochronos has addressed concerns related to generating datasets,
data models, objects and representations of objects.

One existing system implements data mining to determine patterns
from spatial data.  See Han et al., "GeoMiner: A System Prototype for
Spatial Data Mining," Proceedings of the ACM SIGMOD International
Conference on Management of Data, 1997.  Other prototype systems
implement data mining to determine patterns from temporal data.  See
Spiliopoulou, "Discovering Patterns in Sequences," Dagstuhl Seminar
98471, Dagstuhl, Germany, 1998; and Han et al., "Efficient Mining of
Partial Periodic Patterns in Time Series Database," Proceedings of
International Conference on Data Engineering, 1999.

In Spiliopoulou, the data mining is performed on a time dimension
as an ordered lattice, i.e., the only operands on the time variable are

"before" and "after." Such data mining over the ordered lattice is not performed over time as a continuous variable but on time as a sequential variable. More recent work by Spiliopoulou and Han et al. have performed data mining over time as a discrete-valued variable. However, both

5     Spiliopoulou and Han et al. have converted the time variable into a sequence of characters such that data mining for text is used to mine or analyze time-based sequences of events.

Another existing system performs data mining on data having both spatial and temporal components. See Stolorz et al., "Fast Spatio-

10    Temporal Data Mining from Large Geophysical Datasets," Proceedings of the First International Conference on Knowledge Discovery and Data Mining, IEEE Press, 1995. Stolorz et al. determines limited weather patterns by using parallel computers to automatically detect cyclones and blocking conditions from a large geophysical dataset with temporal

15    components.

The existing systems are limited in applying data mining to numerical or one-dimensional data. However, with the increased use of video data, there is a need for a method and system to extend mining to video data, i.e., perform motion mining on a video sequence.

20

## SUMMARY OF THE INVENTION

The present invention is a method and apparatus for performing motion analysis on a sequence of images. Initially, the sequence of images is received from a video source. The sequence of images captures

25    a plurality of objects each moving along a trajectory in an area imaged by the video source. Motion information is extracted from the sequence of images for each of the plurality of objects. Spatial patterns are then determined from the extracted motion information and used for performing functions such as intelligence assessment, traffic control and

30    airport security.

## BRIEF DESCRIPTION OF THE DRAWINGS

The teachings of the present invention can be readily understood by considering the following detailed description in conjunction with the accompanying drawings, in which:

5      FIG. 1 depicts a block diagram of a video processing system for performing motion analysis on a video sequence and displaying the analyzed motion in response to a database query;

FIG. 2A depicts raw data received by a motion extraction system of the video processing system;

10      FIG. 2B depicts exemplary motion information derived from the raw data by the motion extraction system;

FIG. 3 depicts exemplary motion patterns determined from a motion mining system of the present invention;

FIG. 4 depicts a block diagram of one embodiment of the motion

15   mining system;

FIG. 5 depicts an example graphical user interface (GUI) for displaying motion information at the user computer of the video processing system;

FIG. 6 depicts an exemplary set of possible patterns and constraints

20   implemented in the GUI of FIG. 5;

FIG. 7 depicts an exemplary timeline window accessible as a menu option from the GUI of FIG. 5;

FIG. 8 depicts an exemplary details window accessible as a menu option from the GUI of FIG. 5;

25      FIG. 9 depicts a flow diagram of a method for implementing the video processing system of FIG. 1; and

FIG. 10 depicts a flow diagram of a method for implementing the motion mining system of the present invention.

To facilitate understanding, identical reference numerals have been

30   used, where possible, to designate identical elements that are common to the figures.

## DETAILED DESCRIPTION

The present invention is a method and apparatus for performing motion analysis on a sequence of images. Initially, a sequence of images is received from a video source. The sequence of images captures a

5    plurality of objects each moving along a trajectory in an area imaged by the video source. Motion information is extracted from the sequence of images for each of the plurality of objects. Spatial patterns are then determined from the extracted motion information. The invention also determines temporal and spatio-temporal patterns from the extracted

10   motion information. These spatial, temporal and spatio-temporal motion patterns support various applications and functions. For example, these motion patterns are used to perform such functions as intelligence assessment, mission planning, counter terrorism, counter drug traffic, traffic control, airport security, and urban policing.

15       FIG. 1 depicts a block diagram of the video processing system 100 of the present invention. The video processing system 100 performs motion analysis on a video sequence and displays the analyzed motion information in response to a database query. Specifically, the video processing system 100 comprises a video source 105, a motion extraction

20   system 110, a motion mining system 115, a database 120, a server computer 125 and a user interface unit 130.

The video source 105 images a particular area and captures video or an image sequence of the imaged area. Once the video is captured, the video source 105 transmits the captured video to the motion extraction

25   system 110. In one embodiment, the captured video contains a plurality of objects moving in the imaged area. Objects may include people and moving vehicles, e.g., airplanes and automobiles. Examples of the video source 105 include a stationary or moving video camera positioned on a unmanned air vehicle (UAV) or a ground-based video camera, i.e., a

30   camera positioned on a traffic light, and a satellite-based video camera. The video source 105 may also comprise recorded video if the location of objects can be extracted from the recorded video by the motion extraction system 110.

In the present invention, the motion in the video is represented as raw data 201 depicted in FIG. 2A. The raw data 201 comprises coordinates (id, x, y, z, t) in 5-dimensional space, where id represents an object identifier, and x, y and z represent a location of the object at a time t. A maximal sequence of points $\langle$(id, $x_0$, $y_0$, $z_0$, $t_0$), (id, $x_1$, $y_1$, $z_1$, $t_1$), ..., (id, $x_k$, $y_k$, $z_k$, $t_k$)$\rangle$ defines the motion of a moving object, where $t_0 < t_1 < ... < t_k$ and the object moves from location ($x_i$, $y_i$, $z_i$) at time $t_i$ to location ($x_{i+1}$, $y_{i+1}$, $z_{i+1}$) at $t_{i+1}$, for all $0 < i < k$. A contiguous portion of the motion is depicted in FIG. 2A as a "trajectory" 202 of the moving object. The location ($x_i$, $y_i$, $z_i$) of the object, i.e., the raw data 201, is produced by a global positioning system (GPS), while the time $t_i$ represents a timestamp at the video source 105.

The time interval between two successive points is defined by the motion extraction system 110. For a nominal frame rate of 30 frames per second, the time interval may be on the order of one second. In other words, the motion extraction system 110 may periodically process frames, e.g., every thirtieth frame, to reduce the amount of video for processing but maintain an appreciable degree of accuracy. The exact time interval between successive points is dependent on the type of object among other factors, e.g., weather conditions. For example, a video tracking the presence of aircraft would generally require a shorter time interval than a video tracking of the presence of automobiles.

The motion extraction system 110 receives the video or image sequence from the video source 105 and extracts motion information from the received information. An exemplary motion extraction system 110 is provided by the Sarnoff Corporation in U.S. Patent no. 5,259,040, issued to Hanna on November 2, 1993, which is herein incorporated by reference. FIG. 2B depicts exemplary motion information 206 extracted from the trajectory 202 of each moving object by the motion extraction system 100. Examples of such motion information 206 include a trajectory time span, a trajectory region, a trajectory start point, a trajectory end point, a direction of the trajectory, a speed range of the trajectory, an acceleration range of the trajectory, a shape of the trajectory and a path of the trajectory. Additionally, if the received video contains ESD (electronic sensor data), the motion information 206 also includes the geolocation, i.e.,

geographical position, of the moving objects. The motion information 206 for each trajectory 202 is then transmitted to the motion mining system 115 and the database 120.

The motion mining system 115 receives the extracted motion
5    information from the motion extraction system 110 and determines spatial, temporal and spatio-temporal patterns from the motion information 206 received from the motion extraction system 110. These motion patterns are then transmitted to and stored in the database 120. FIG. 3 depicts exemplary motion patterns 300 as determined by the motion
10   extraction system 110. The motion patterns 300 are provided in response to a database query 310 at the user computer 130. Examples of these motion patterns 300 include but are not limited to: an object stopping, a fast moving object, an active region, a source region, a "beaten" path, a road or route, a convoy, a violation of a traffic light and illegal parking.

15   In one embodiment, the motion mining system 115 may determine spatial patterns without regard to a particular time. The motion mining system 115 may perform "routes clustering," i.e., determine the existence of "routes" by clustering or grouping of trajectories 202 of at least two objects traveling along the same path. Each route is determined in an
20   iterative manner. For example, if any portion of a trajectory 202 is close, e.g., within a threshold distance, to a previously considered trajectory or a previously considered route, then the portion is combined to form a new route.

After clustering or grouping the trajectories into routes, the motion
25   mining system 115 may also cluster each route in the time dimension. The clustering of routes in the time dimension represents a "busy time" along the route. For example, the motion mining system 115 determines whether the number of trajectories along the route exceeds a threshold number at different times. To determine such "busy times" along each
30   route, the motion mining system 115 uses a clustering process, e.g., a "K-means" clustering process. Examples of the K-means process are shown in Bradley et al., "Refining Initial Points for K-Means Clustering," Proceedings of the Fifteenth International Conference on Machine

Learning, 1978, pages 91-99; and Hartigan et al., "A K-Means Clustering
Algorithm," Applied Statistics, Vol. 28, No. 1, 1979, pages 100-08.

   The determined busy time represents a particular time or time
interval when the number of trajectories in the route is greater than a
5  threshold number. The exact value of the threshold number is dependent
upon different factors, e.g., the type of object, the time interval under
consideration and the region or location of the imaged area. For example,
a busy time along a particular route may represent a morning rush hour.

   The motion mining system 115 may also cluster or group
10  trajectories to determine popular origins and popular destinations. In one
embodiment, the motion mining system 115 uses the start and end points
of various trajectories to determine popular source and destination points.
If the number of trajectories 202 starting from the region or location is
greater than a threshold number, the region or location is identified as a
15  popular origin or source point. Similarly, if the number of trajectories 202
ending at a region or location is greater than the threshold number, the
region or location is identified as a popular destination or sink point. The
exact value of the threshold number is dependent upon different factors,
e.g., the type of object, the time interval under consideration and the
20  region or location of the imaged area. As with the clustering of routes
along the time dimension, the motion mining system 115 may use a
clustering process, e.g., a K-means clustering process, to identify regions
containing many origins of trajectories and regions containing man
destinations of trajectories.

25   Once the spatial patterns, e.g., routes, source points and sink
points, are determined, the motion mining system 115 determines
whether temporal or periodic patterns exist along the routes. Namely, the
motion mining system 115 determines, for each "time scale" within a
predefined set of time scales, whether there is any temporal pattern or
30  periodicity in the time dimension along each route.

   A time scale represents a time interval where two events are
considered to have simultaneously occurred if the events occurred within
the same time interval. For example, if the time scale is one hour, a first
event at 10:12 AM is considered to have simultaneously occurred with a

second event at 10:43 AM. By using a predefined time scale, the motion mining system 115 identifies periodic behavior over time intervals. For example, if the motion mining system 115 is to detect events occurring every Tuesday morning using an one hour time scale, then the following

5    event sequence may be identified as a pattern: 12/28/99 at 10:12 AM, 1/4/00 at 10:43 AM, 1/11/00 at 10:21 AM, and 1/18/00 at 10:56 AM. As such, the motion mining system 115 detects events periodically occurring within a time range and is not limited to strictly periodic events, i.e., events occurring at exactly the same time. Exemplary time scale values are one

10   minute, five minutes, one hour, one day and one week. However, a person of ordinary skill may also use other time scale values to determine periodicity.

The motion mining system 115 may also determine a "time correlation" between different routes for different time scales. Namely,

15   the motion mining system 115 determines, for each pair of routes separated by less than a threshold distance apart, whether a trajectory 202 in one route is followed at the same time interval by a trajectory 202 in another route. For example, if the time scale is one hour, the following events is considered a four hour time correlation between a first route and

20   a second route: events occurring on 12/28/99 at 10:12 AM, 1/4/00 at 10:43 AM, 1/11/00 at 10:21 AM and 1/18/00 at 10:56 AM over the first route, and events occurring on 12/28/99 at 2:33 PM, 1/4/00 at 2:18 PM, 1/11/00 at 2:26 PM and 1/18/00 at 2:34 PM over the second route.

The motion mining system 115 is not limited to the above-identified

25   patterns. For example, the motion mining system 115 may apply a pattern operator 210 to determine a time periodicity of a particular object within a route. The motion mining system 115 may also identify fast-moving objects and slow-moving objects having trajectory speeds within particular ranges. Additionally, the motion mining system 115 may apply a

30   deviation operator 212 to determine any deviations or violations from a previously determined pattern.

The above-mentioned motion patterns are used in a variety of practical applications. Such applications that use these motion patterns include: discovering periodic patterns of flights, determining whether

different flights are time-correlated, finding regions of heavy influx of
vehicles over the last week, finding regions of heavy outflow of vehicles,
predicting the location of an object in the next hour, and predicting any
suspicious patterns between two objects.  Additionally, applications that

5    use deviations of motion patterns include: finding objects flying in a region
having no commercial routes, detecting a fast moving object in a no-fly
zone, determining whether a vehicle has reversed its path near a road
block, determining whether a vehicle is moving faster than average,
detecting speeding objects, and detecting objects with unusual

10   acceleration.  These applications are exemplary and are not considered to
be limiting in any manner.

The database 120 contains at least the above- identified motion
patterns from the motion mining system 115 and motion information from
the motion extraction system 110.  The motion patterns and motion

15   information represent motion of a plurality of objects in a imaged area and
over a particular time interval.  The server computer 125 accesses and
uses the data in the database to perform calculations in response to a
query from the user computer 130.  The query results are displayed as a
graphical user interface (GUI) at the user computer 130.  An exemplary

20   GUI is further described with respect to FIGS. 5-8.

FIG. 4 depicts one embodiment of the motion mining system 115 of
the present invention.  The motion mining system 115 is embodied as a
computer 400 comprising a memory 402, a central processing unit (CPU)
404, a signal interface 406 and support circuits 408.  The memory 402

25   stores software programs, e.g., a motion mining program 410 and a K-
means clustering program 412.  The motion mining program 410, when
executed by the CPU 404, is used to implement the motion mining system
115.  The K-means clustering program 412 is used to determine source
points, target or destination points, and the busy times along routes.

30   The signal interface 406 receives motion information from the
motion extraction system 110.  Once the motion information is received at
the signal interface 406, the CPU 404 executes instructions or commands
in the motion mining program 410 to determine spatial patterns, temporal
patterns and spatio-temporal patterns from the received motion

information.  The CPU 404 may use well-known support circuits 408 to implement the motion mining program 410.  Examples of support circuits 408 may include a clock, a power supply, a cache memory, and the like. The signal interface 406 then transmits the patterns to the database 120.

5      Examples of the signal interface 406 include a cable modem, a network card, and the like.

FIG. 5 depicts an exemplary graphical user interface (GUI) 500 for displaying motion information and motion patterns.  A user may use the GUI 500 to specify a database query on the motion patterns and motion

10     information stored in the database 120.  The results of the query are then displayed on the GUI 500.  Specifically, the GUI 500 comprises menu window 510, a map window 520 and a timeline window 530.

The menu window 510 includes a search tab 512, a details tab 514 and a timeline tab 516.  The menu window 510 may also include additional

15     tabs, e.g., a messages tab, an alert tab and a database tab.  If the search tab 512 is selected, the menu window 510 displays a search window 550 containing a list 552 of predefined queries and fields 554, 556, 558 and 560 to define a selected query.  For example, the list 552 may include queries to determine busy source points, routes and deviations thereof, and a time

20     correlation between different routes.

The fields 554-560 are used to define the query with selected categories motion patterns and motion information 206 and with selected values of constraints. The type and number of available fields or option windows 554-560 is dependent on the type of query to perform.  The

25     constraints selected in the fields 554C, 556C and 558C are limitations to a particular motion pattern or a particular type of motion information 206. An exemplary set 600 of motion patterns, motion information 206 and constraints are depicted in FIG. 6.  Such constraints, shown as shaded in the set 600, may define a speed range, an acceleration range, a direction of

30     an object, a type of object, a time interval relative to an event, and a region relative to a trajectory 202.

The search window 550 depicted in FIG. 5 indicates the selection of a query "pln" as indicated in field 562.  This query is used to determine the existence of a particular type of route.  The query is specified by a speed

category in field 554, a crossing condition in field 556, a time frame in field
558 and an existence of off-norm traffic in field 560. Constraints are
provided in field 554C for a speed range, in field 556C for a region being
crossed, and field 558C for objects travelling in a specified time frame.

5          The selection of the timeline tab 516 results in the display of a
timeline window 700 depicted in FIG. 7. The timeline window 700
contains fields for defining the start and end of a time frame or time
interval of interest. Once the query is performed and the query result is
displayed on the map window 520, the user may select the details tab 514 to
10        display a details window 800 depicted in FIG. 8. The details window 800
indicates information of each trajectory that satisfies the query specified in
the query window 550. For example, the details window 800 may indicate
the object identifier and the start time for the trajectory of the object.

          The map window 520 displays the routes that satisfy the query
15        specified in the search window 550. Namely, the map window provides a
spatial representation of an area captured in the video. The creation of the
map window 520 includes the display of a background image of the imaged
area and then overlaying the background image with routes that satisfy
the query.

20        The timeline window 530 displays the object identifier and time span
of each trajectory in the routes shown in the map window 520. Thus, the
timeline window 530 provides a temporal representation of the trajectories
for each route. The range of time is specified in the timeline window 700.
Specific information for each trajectory is displayed in the details window
25        800.

          FIG. 9 depicts a flow diagram of a method 900 for implementing the
video processing system 100. The method 900 starts at step 902 and
proceeds to step 904, where the video source 105 captures video of the
imaged area of interest. At step 906, the method 900 uses the motion
30        extraction system 110 to extract motion information 206 from the video.
Motion information 206 includes information relating to a trajectory 202 of
a moving object captured in the video. Examples of motion information
206 include a path of the trajectory 202, a speed range of the trajectory 202,
and a start point of the trajectory 202.

At step 908, the method 900 stores the extracted motion information 206 in the database 120. The method 900 uses the extracted motion information at step 910, where the inventive motion mining system 115 determines motion patterns from the extracted motion information 206.

5      Step 910 is further described with respect to FIG. 10. The method motion patterns are stored in the database 120 at step 912.

The method 900 proceeds to step 914, where a server computer 125 performs a query on the stored motion information 206 and motion patterns. The query is performed in response to a command from a user

10     at the user computer 130. The query may contain constraints used to specify particular categories or ranges of motion information 206 and motion patterns. At step 916, the motion information 206 and motion patterns specified in the query are retrieved from the 120. The method 900 proceeds to step 918, where the results of the query are displayed through a

15     graphical user interface (GUI) at the user computer 130. Steps 914, 916 and 918 are used to perform each query specified by the user. The method 900 proceeds to end at step 920.

FIG. 10 depicts a flow diagram of a method 1000 for implementing the motion mining system 115 of the present invention. The motion

20     mining system 115 performs the method 1000 in accordance to commands in the motion mining program 410. Specifically, the method 1000 starts at step 1002 and proceeds to step 1004, where motion information 206 is received from the motion extraction system 110.

The motion information is used to determine routes at step 1006.

25     Routes represent the grouping or clustering of two or more trajectories having a common path. The information on the routes is prepared for storage at step 1008. For example, information from step 406 may be temporarily stored in the memory 402 or support circuits 408 of the motion mining system 115 or may be directly stored in the database 120.

30     At step 1010, the method determines busy times along each of the routes. Specifically, for each route, step 410 performs clustering of the trajectories along the time dimension. The busy times or intervals represent the times when the number of trajectories is greater than a

predetermined threshold number. The information from step 1010 is prepared for storage at step 1008.

The method 1000 also uses the information on routes in step 1012, where periodic patterns are determined for each route. The

5    determination of periodic patterns uses the concept of a time scale that represents a time interval where two events are considered to have occurred simultaneously if the events occurred within the same time interval. As such, step 1012 is not limited to strictly periodic patterns but captures additional periodic patterns within a predefined time interval or

10   time scale. The information from step 1012 is also prepared for storage at step 1008.

At step 1014, the method 1000 also uses information from step 1006 to determine time correlations between two different routes for different time scales. For each pair of trajectories 302 separated within a threshold

15   distance, step 1014 determines whether a trajectory 302 in a first route is followed at the same time interval by another trajectory 302 in a second route. The information on time correlation is prepared for storage at step 1008.

The method 1000 uses the received motion information 206 to

20   determine popular origins and destinations at step 1016. The popular origins and destinations are determined by grouping or clustering common start points and common end points of trajectories 302. For example, step 1016 identifies a popular origin if the number of trajectories having a common start point is greater than a threshold number.

25   Similarly, step 1016 identifies a popular destination if the number of trajectories having a common end point is greater than a threshold number. The information on popular origins and destinations is prepared for storage at step 1008. The method 1000 proceeds to end at step 1018 once all the motion patterns are determined from steps 1006, 1010, 1012, 1014

30   and 1016.

Although various embodiments which incorporate the teachings of the present invention have been shown and described in detail herein, those skilled in the art can readily devise many other varied embodiments that still incorporate these teachings.